Analysis of a Measurement of ^{12}C(n,2n)^{11}C Cross Sections

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I. Abstract

In inertial confinement fusion (ICF), nuclear fusion reactions are initiated by bombarding a small fuel pellet with high power lasers. One ICF diagnostic tool involves placing graphite discs within the reaction chamber to determine the number of high-energy neutrons. This diagnostic requires accurate ^{12}C(n,2n)^{11}C cross sections, which have not been previously well measured. An experiment to measure this cross section was conducted at Ohio University, in which DT neutrons irradiated polyethylene and graphite targets. The neutron flux was determined by counting recoil protons from the polyethylene in a silicon dE-E detector telescope. Preliminary cross sections were calculated using the incident neutron flux and the number of ^{11}C nuclei in the graphite and polyethylene targets determined by counting, in a separate counting station, the gamma rays resulting from the positron decay of ^{11}C. This poster will present the data analysis techniques used to determine theses cross sections and the calculation of the corrections needed to account for the detector and target geometry.
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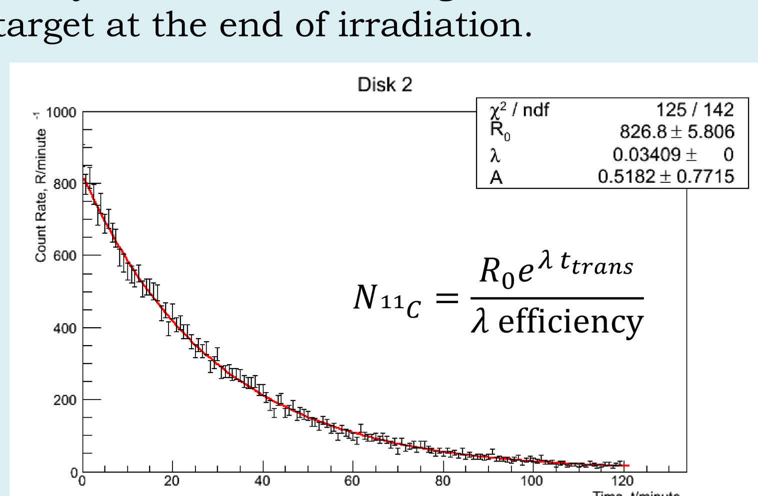
III. ^{12}C(n,2n)^{11}C Cross Section (σ_{n2n})

The rate of change of the number of ^{11}C nuclei $N_{^{11}C}$ is the difference of the growth rate (proportional to the rate neutrons hit the target N_n) and the decay rate (proportional to the number of ^{11}C nuclei $N_{^{11}C}$). This can be solved for the cross section σ_{n2n} in terms of the proton detection rate N_p by utilizing the ratio N_p/N_n from the geometry of the system.

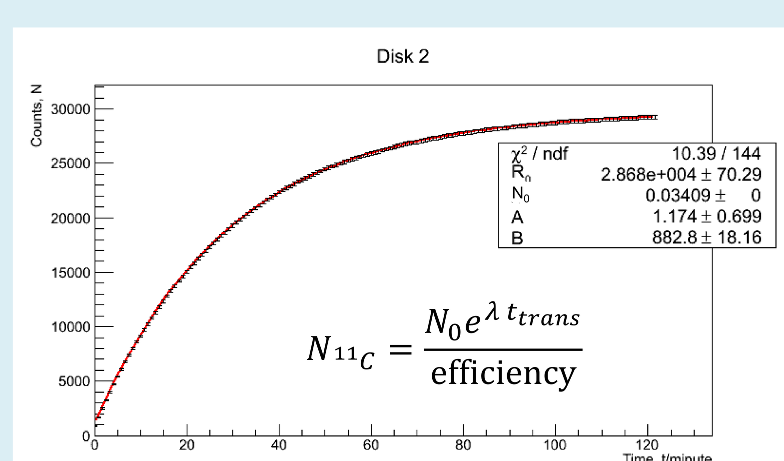
$$\frac{dN_{^{11}C}}{dt} = \sigma_{n2n} N_n T_C - \lambda N_{^{11}C} \qquad \sigma_{n2n} = \frac{N_{^{11}C}\,\lambda}{N_n T_C (1-e^{-\lambda t})} = \frac{N_{^{11}C}\,\lambda}{T_C (1-e^{-\lambda t})}\left(\frac{N_p}{N_n}\right)\frac{1}{N_p}$$

IV. ^{11}C Nuclei Count ($N_{^{11}C}$)

The number of ^{11}C nuclei $N_{^{11}C}$ in the target was determined by counting the back-to-back gamma rays resulting from the positron decay of ^{11}C into ^{11}B. Fits were made of either the decay curve of ^{11}C or the growth curve of ^{11}B to determine the total number of ^{11}C in the target at the end of irradiation.

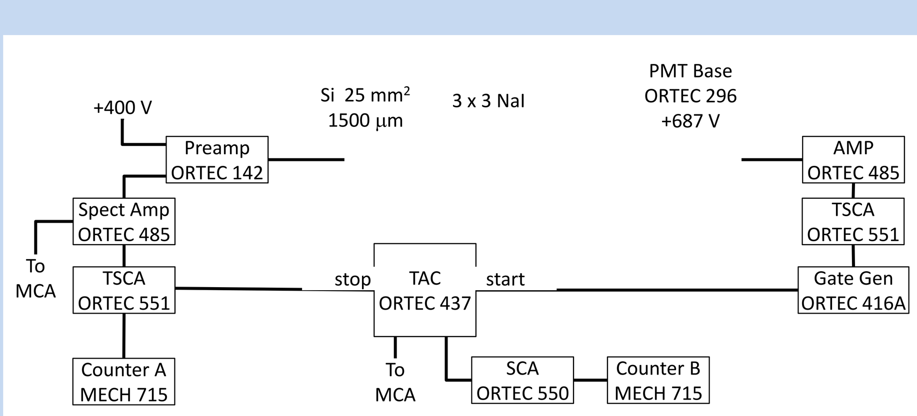


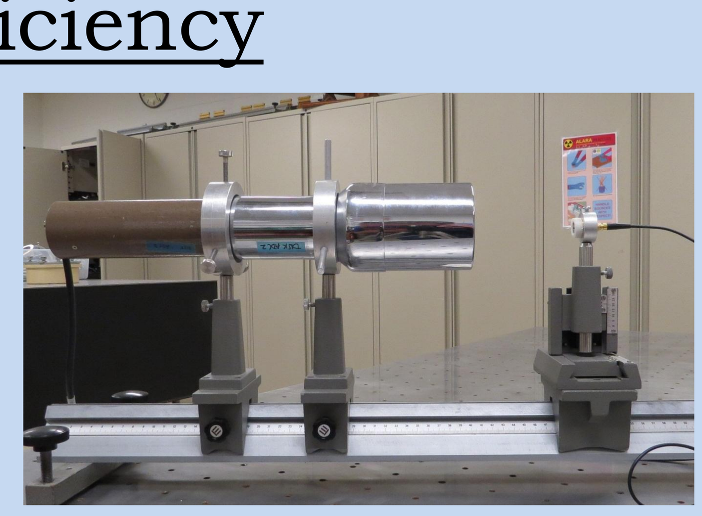
^{11}C decay curve $R(t) = R_0 e^{-\lambda t} + A$



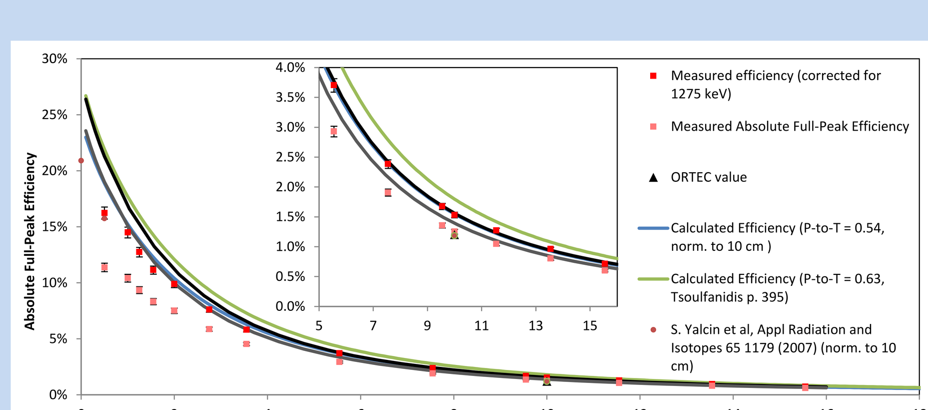
^{11}B growth curve $N(t) = N_0(1-e^{-\lambda t}) + At + B$

V. Detector Efficiency





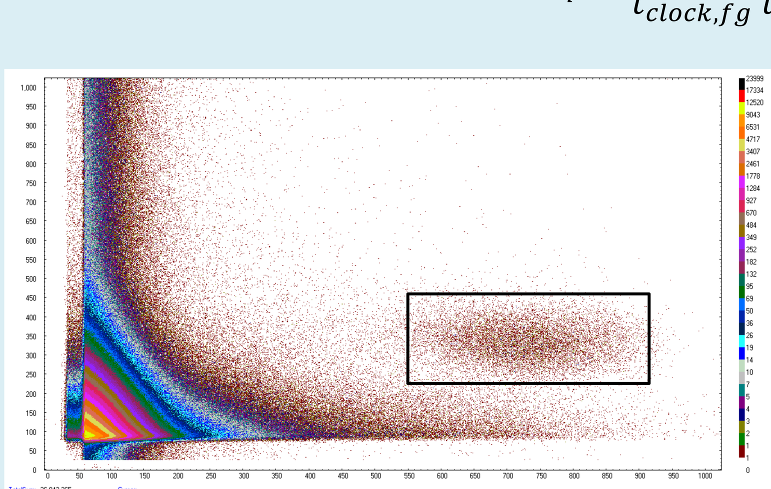
The absolute efficiency of the NaI detectors used must be determined at short distances for an accurate calculation of the total number of $N_{^{11}C}$, the number of ^{11}C present in the target after activation.

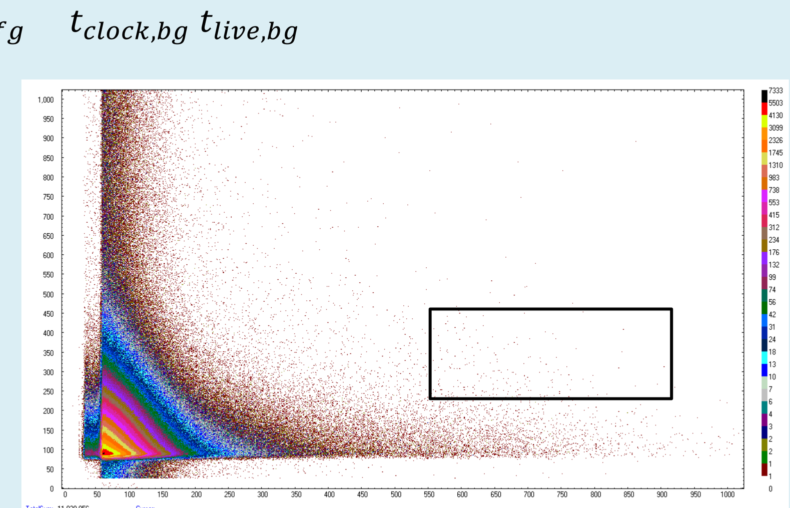


VI. Proton Detection Rate (N_p)

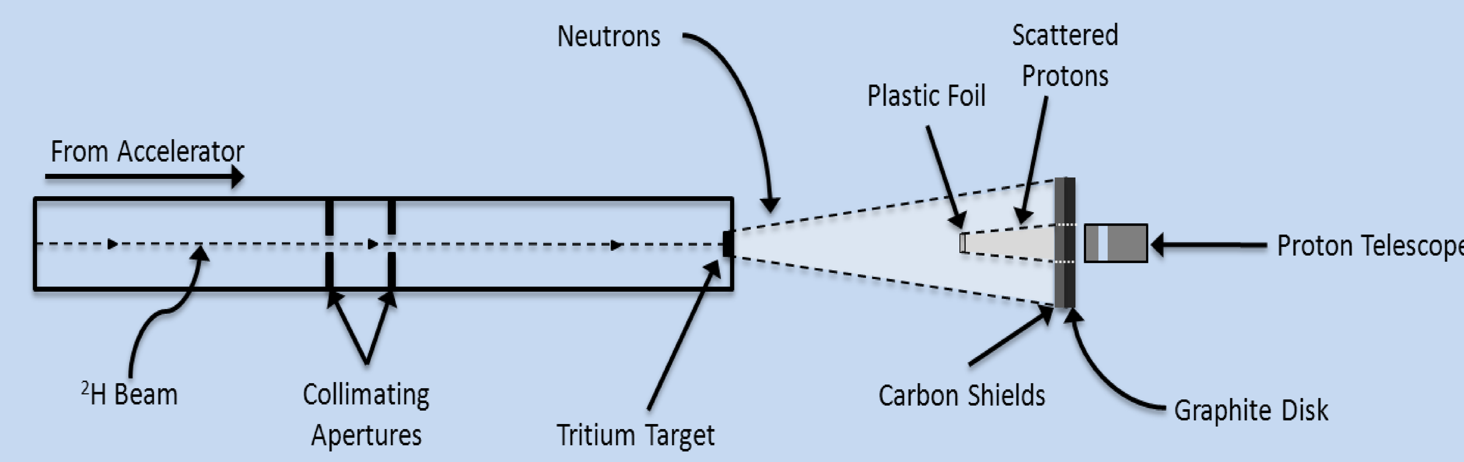
The number of protons detected by the proton telescope was measured for both the foreground (with polyethylene) and background (without polyethylene). The absolute proton count rate N_p was determined by subtracting.

$$N_p = \frac{N_{p,fg}}{t_{clock,fg}\, t_{live,fg}} - \frac{N_{p,bg}}{t_{clock,bg}\, t_{live,bg}}$$



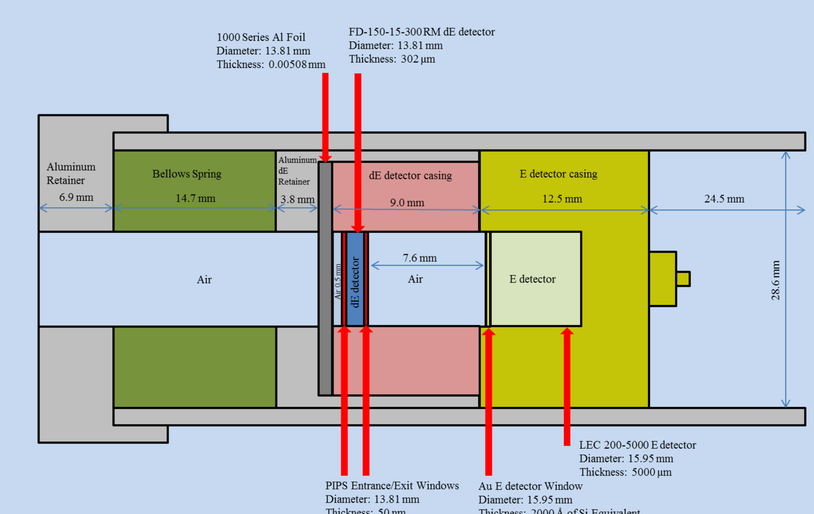


II. Experiment

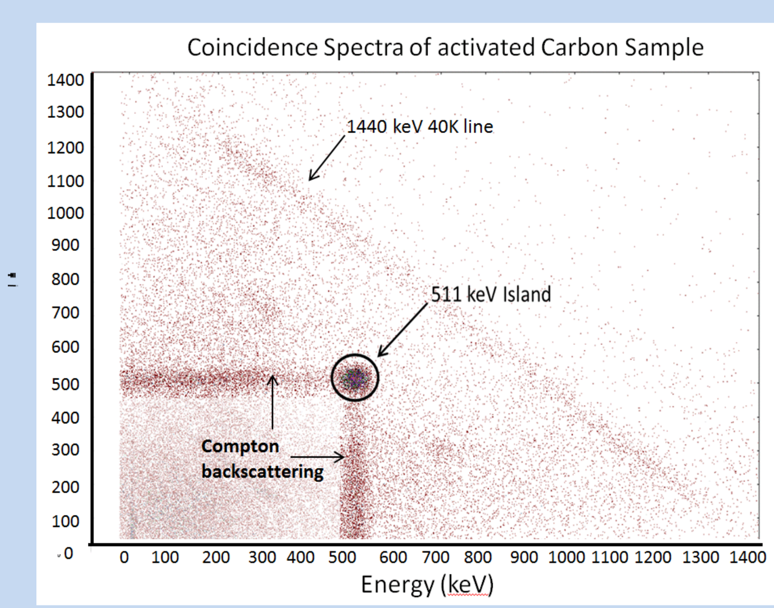


Deuterons were accelerated to energies between 3.5 and 8.285 MeV and allowed to strike a titanium tritide foil. Beam currents were typically between 0.5 and 1.0 μA. Before striking the target, the deuteron beam was defocused by a pair of quadrupole magnets and allowed to pass through a collimator to produce a uniform spot.

D* + T → α + n*
n* + ^{12}C → 2 n + ^{11}C
n* + p → p* + n



In order to determine the neutron flux (N_n), protons from neutron-proton elastic scattering were counted (N_p) in a ΔE-E detector telescope.

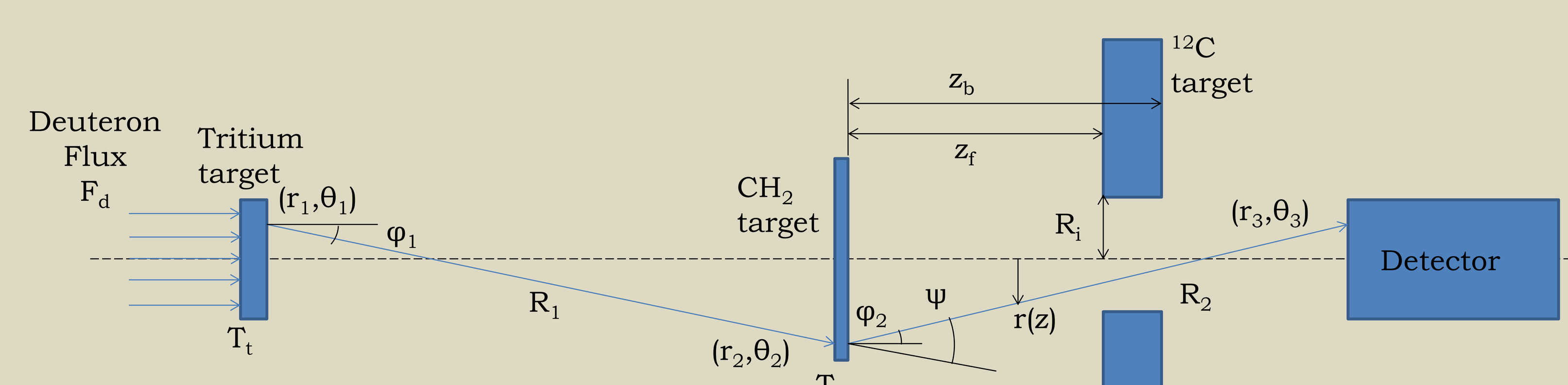


^{11}C → ^{11}B + e$^+$
e$^+$ + e$^-$ → 2 γ_{511keV}

After an activation period of approximately 6 half lives, the targets were removed to a counting station. The rate of back-to-back gamma rays resulting from positron annihilation was used to determine the number ($N_{^{11}C}$) of ^{11}C nuclei present.

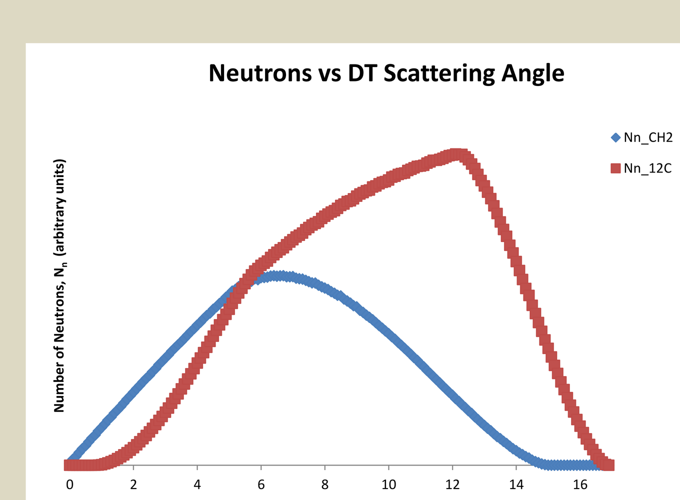
VII. Proton to Neutron Ratio (N_p/N_n)

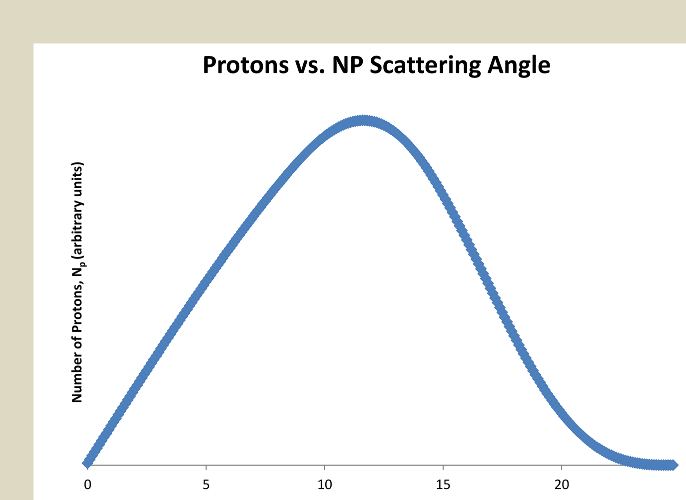
The ratio between the number of protons detected by the proton telescope and the number of neutrons hitting a target can be calculated based upon the geometry of the system.



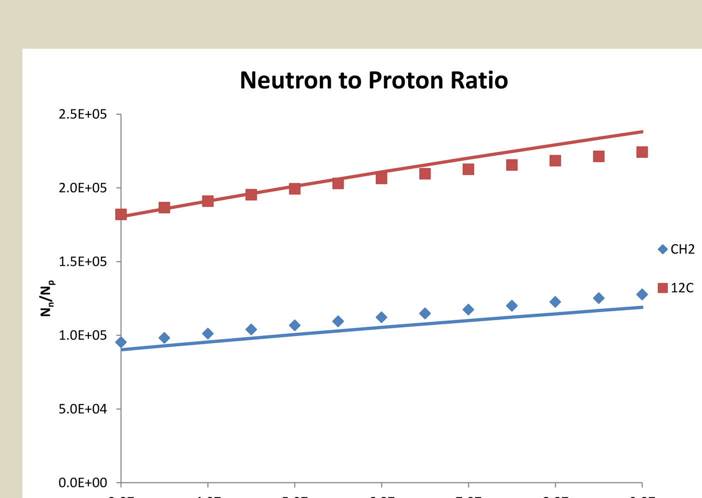
$$N_n(\mathrm{CH_2}) = \int_0^{2\pi}\int_0^{R_{CH_2}}\int_0^{2\pi}\int_0^{R_t} \sigma_{dt}(\phi_1, E_d)\, F_d\, T_t\, r_1 dr_1 d\theta_1 \frac{\cos\phi_1}{R_1^2} r_2 dr_2 d\theta_2$$

$$N_p = \int_0^{2\pi}\int_0^{R_d}\int_0^{2\pi}\int_0^{R_{CH_2}}\int_0^{2\pi}\int_0^{R_t} \begin{Bmatrix} 0, & r(z_f) \geq R_i \text{ or } r(z_b) \geq R_i \\ \sigma_{dt}(\phi_1)\,\sigma_{np}(\psi, E_n(\phi_1)) F_d T_t \dfrac{T_H}{\cos\phi_1} & \end{Bmatrix} r_1 dr_1 d\theta_1 \frac{\cos\phi_1}{R_1^2} r_2 dr_2 d\theta_2 \frac{\cos\phi_2}{R_2^2} r_3 dr_3 d\theta_3$$

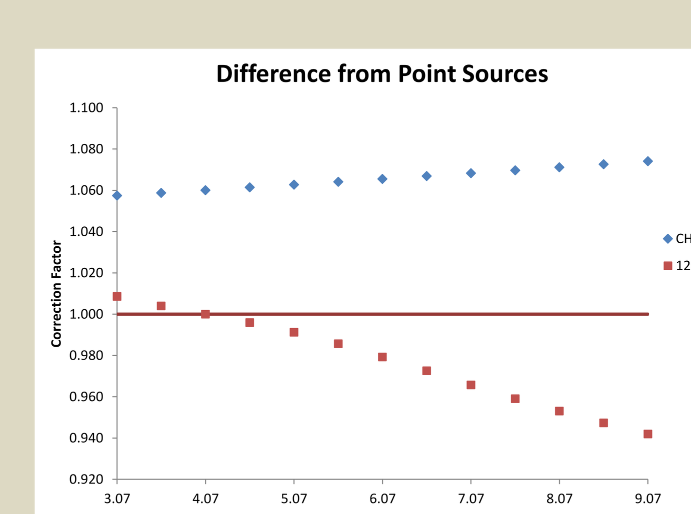




The angular distributions of neutrons hitting the polyethylene and graphite targets and protons hitting the detector. The majority of scattering events have angles larger than 0°.



The neutron to proton ratio (N_n/N_p) was calculated for both the graphite and polyethylene targets. The solid lines are the ratios for "point targets", and the symbols the ratios for the extended targets.



The amount that the extended source calculation differed from the point source calculation (used for preliminary results) was found to be less than 8%.